The Atmospheric Energy Budget and Large-Scale Precipitation Efficiency of Convective Systems during TOGA COARE, GATE, SCSMEX, and ARM: Cloud-Resolving Model Simulations

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ABSTRACT

A two-dimensional version of the Goddard Cumulus Ensemble (GCE) model is used to simulate convective systems that developed in various geographic locations (east Atlantic, west Pacific, South China Sea, and Great Plains in the United States). Observed large-scale advective tendencies for potential temperature, water vapor mixing ratio, and horizontal momentum derived from field campaigns are used as the main forcing. The atmospheric temperature and water vapor budgets from the model results show that the two largest terms are net condensation (heating/drying) and imposed large-scale forcing (cooling/moistening) for tropical oceanic cases though not for midlatitude continental cases. These two terms are opposite in sign, however, and are not the dominant terms in the moist static energy budget.

The balance between net radiation, surface latent heat flux, and net condensational heating vary in these tropical cases, however. For cloud systems that developed over the South China Sea and eastern Atlantic, net radiation (cooling) is not negligible in the temperature budget; it is as large as 20% of the net condensation. However, shortwave heating and longwave cooling are in balance with each other for cloud systems over the west Pacific region such that the net radiation is very small. This is due to the thick anvil clouds simulated in the cloud systems over the Pacific region. The large-scale advection of moist static energy is negative, as a result of a larger absolute value of large-scale advection of sensible heat (cooling) compared to large-scale latent heat (moistening) advection in the Pacific and Atlantic cases. For three cloud systems that developed over a midlatitude continent, the net radiation and sensible and latent heat fluxes play a much more important role. This means that the accurate measurement of surface fluxes and radiation is crucial for simulating these midlatitude cases.

The results showed that large-scale mean (multiday) precipitation efficiency (PE) varies from 24% to 31% (or 32% to 45% using a different definition of PE) between cloud systems from different geographic locations. The model results showed that there is no clear relationship between the PE and rainfall, the positive cloud condensation (condensation plus deposition), or the large-scale forcing. But, the model results suggest that cases with large, positive net condensation terms in the moist static energy budget tend to have a large PE.

The PE and its relationship with relative humidity and the vertical shear of the horizontal wind are also examined using 6-hourly model data. The model results suggest that there is no clear relationship between the individual PE and total mass-weighted relative humidity or the middle- and upper-tropospheric moisture for each case. The model results suggest that for the west Pacific and east Atlantic cases, PE slightly decreases with increasing middle-tropospheric wind shear in low to moderate shear regimes. The correlation (based on the best polynomial fit) is quite weak however. No strong relationship between PE and wind shear was found for the South China Sea and cases over the United States.

1. Introduction

Cloud-resolving (or cumulus ensemble) models (CRMs) are one of the most important tools used to establish quantitative relationships between diabatic heating and rainfall. This is because latent heating is dominated by phase changes between water vapor and small, cloud-sized particles, which cannot be directly detected. CRMs have sophisticated (though still parameterized) microphysical processes that can simulate the conversion of cloud (liquid and solid) condensate into

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